Quartz Contents of Pelagic Sediments of the Pacific Ocean[1]

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Abstract

The quartz contents of pelagic clays from the Eastern Pacific Ocean show a marked latitudinal dependence with a maximum around 30° N. Present evidence indicates that the quartz is mainly transported to the deposits through the atmosphere and that the observed distribution is probably related to the latitudinal values of the atmospheric wind fluxes and exposed arid land areas. A number of sediments display a distinct change in quartz content with depth. In all cases there is a marked decrease going from the recent to the older strata. It is suggested that the changes indicate a major climatic change that occured sometime during the Late Tertiary.

Quartz is one of the major minerals in igneous rocks (12 – 20% on the average) and is one of the most resistant substances to chemical and mechanical weathering (PETTIJOHN, 1957), yet its role in the major sedimentary cycle is poorly understood. Few determinations of its concentration in recent marine sediments have been made. CORRENS (1937), REVELLE (1944), KUENEN and NEEB (1943), and GRIM ET AL. (1949) give semi-quantitative estimates in their studies, while REVELLE ET AL. (1955) present figures of 2 – 5% in Pacific buff clays. Inasmuch as the total amounts of quartz in sediments may serve as an indicator both of the lithogenous contribution as well as of the mechanics of deposition, it appeared worthwhile to make an intensive quantitative study of its space and time distribution in the Pacific Ocean deposits.

The determinations were made by x-ray diffractometry and the results are reproducible to ±3% of the absolute values obtained with a minimum sensitivity of 0.3% quartz. The details of the method will be published elsewhere.

The quartz particles in the sediments are found as chips and shards and are well sorted with maximum concentrations between 1 and 20 microns (Figure 1). There is no microscopic evidence for crystal overgrowth. Quartz bipyramids, characteristic of volcanic beta quartz, have not been observed in any of the samples. There is no evidence for the authigenic formation of quartz in the marine environment. INGERSON (1955) points out that there is no known example of the crystallization of quartz from aqueous solutions below 100° C. and no conversion of biogenous silica to quartz has been observed in unmetamorphosed sediments dating back to the Miocene (BRAMLETTE, 1946). Inspection of biogenous silica in sediments as old as Paleocene showed no significant conversion of opal to quartz. In this presentation almost all of the samples are apparently of Miocene age or younger.

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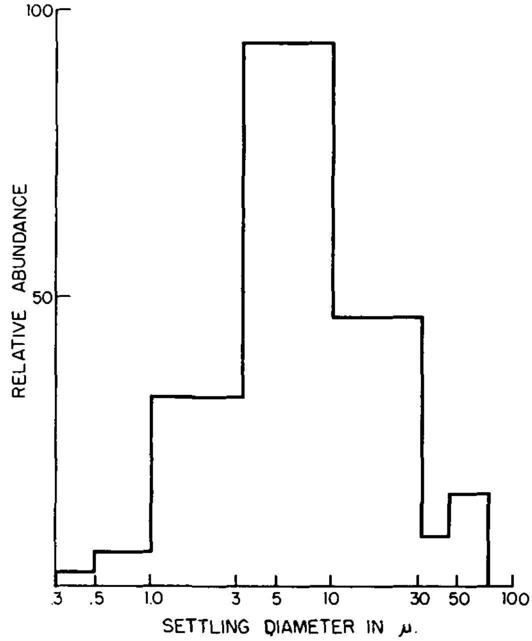

Fig. 1. The size distribution of quartz in pelagic clay sample PAS 19121 (Lat. 19°49«N; Long. 121°43.5«W; and depth 4,350 meters).

Space and Time Distribution of Quartz

The two principle results of the study are the space and the time distribution of quartz in the pelagic sediments. The major feature of the surface distribution in the Eastern Pacific is a marked latitudinal dependence of the quartz concentration with a maximum at around 30° North and decreasing in both the north and south directions (Figure 2). The values are for the calcium carbonate free fraction of the sample. Perturbations of this general pattern can be effected in the following ways. The introduction to the deposits of biogenous silica or carbonates reduces the observed quartz values. This is evident in the highly diatomaceous samples from the Bering Sea and from the area to the immediate south of the Aleutian trench and in the siliceous and carbonaceous deposits of the equatorial belt.

A second type of dilution is found in the quartz distribution in the sediments surrounding the Hawaiian Islands (Figure 3). These islands belong to a basaltic province and the magmas are strikingly deficient in quartz compared to the average abundance in igneous rocks. The deposits are diluted to a distance of 150 miles north by the weathering products from the erosion of the islands. The Hawaiian Arch appears to form the outer margin of transport of materials. Again, volcanic ash layers in cores from the Gulf of Alaska show smaller values of quartz than adjacent strata.

The latitudinal pattern can also be disturbed by turbidity current deposits which occur on abyssal plains, walls and bottom of deep trenches and archipelagic aprons. For example, on the shoreward side of the Acapulco trench area, where turbidity flows are thought to occur, the quartz ranges between 12 and 24%, while in the seaward deposits of the trench, free of such flow from the coastal area, the values are of the order of 8%. Further evidence of the influence of turbidity currents upon the quartz contents of sediments will be discussed below.

A number of red clay cores display a distinct change in the characteristics of the sediment type with depth. Such variations exist either as discrete discontinuities or gradual changes. In all such cases, there is a marked decrease in the quartz concentration in the lower levels of the cores (Table 1). The quartz values above and below the zones of change are remarkably uniform (Figure 4). In most cases the upper sediment contained a Quarternary radiolarian fauna. Three of the cores contained Middle Tertiary radiolarian fauna in the lower quartz poor strata (Riedel, W., personal communication). The remaining cores contained no age-indicating fossils below the discontinuity.

Sources of the Quartz

Two significant problems relative to these results are the sources and modes of transport of the quartz. Since we have ruled out an authigenic origin, there remains the consideration of the relative contributions of continental detritus and marine volcanic ejecta. The quartz contents of sediments containing large amounts of pyroclastics are notably low. The presence of quartz as chips and shards and the absence in the sediments of quartz phenocrysts, typical of volcanic lava, support the argument of a continental source.

The consistent appearance of the same broad band (3.18 – 3.24Å°) in the x-ray diffraction spectra of pelagic clays in the Pacific represents a composite of feldspar peaks. This indicates contributions from many sources with sub-

TABLE 1

Depth Distribution of Quartz in North Pacific Sediments

Core	Zonation (cm.)		Contact	Quartz Content		Samples Run	Notes
	Upper	Lower		Upper	Lower		
Chubasco 10 10° 21.4′ N 124° 26.3′ W 4,645 meters	0—86	86—120	Discon-tinuous	8%	3%	Upper: 0—4; Lower: 116—120	Upper zone contains Quaternary radiolaria with admixed Tertiary. No age-indicating fossils in lower zone.
Chubasco 9 10° 18.5′ N 125° 27.2′ W 4,545 meters	0—32	32—100	»	8%	3%	Upper: 0—4, 16—20; Lower: 44—48, 96—100	Upper zone contains Quat. rads. with admixed Tertiary. Lower zone contains Middle Tert. rads.
Mid-Pac 14 9° 57.7′ N 145° 12.7′ W 5,232 meters	0—4½	4½—79	»	8%	2%	Upper: 3—4; Lower: 74—76	Upper zone contains Quat. rads. with much admixed Tert. Lower zone contains Middle and Early Tert.
Capricorn 49 BP 9° 17′ N 124° 09′ W 4,410 meters	0—124	228—832	Gradational from 124 to 228 cm.	8%	3%	Upper: 0—4; Lower: 300—304	Upper zone to at least 40 cm. probably Quat. with Tert. admixture. Lower zone Middle Tert.
Capricorn 50 BP 14° 55′ N 124° 12′ W 4,270 meters	0—302	302—812	Discon-tinuous	9.8 ± 0.9%	2.8 ± 0.5%	Upper: 0—302 (72 samples); Lower: 302—812 one sample every 20 cm. (18 samples)	Upper zone perhaps Quat. Lower zone no age-indicating fossils.
Chinook 2 35° 09′ N 157° 17.5′ W 5,610 meters	0—21	21—54	»	16%	6%	Upper: 0—4; Lower: 51—54	No age-indicating fossils in core.
Chinook 4 42°29.9 N 162°8.2′W 5,400 meters	0—126	126—157	»	15%	12%	Upper: 0—5, 10—12, 12—16; Lower: 128—132, 140—144, 144—148, 154—157	Upper zone Quat. rads. Lower zone no age indicating fossils.

sequent mixing. The continents provide the necessary variety of feldspars to produce such a composite peak. Further, in samples from areas where pyroclastics are abundant in the deposits, the composite feldspar band is overshadowed by sharp peaks characteristic of the feldspars from local sources of volcanic activity.

Transport Mechanics

It is difficult to conceive of the water transport of quartz particles with their observed size distributions from the continental boundaries to pelagic areas, which are inaccessible to turbidity flow or ice rafting. For example, the area of abundant quartz, north of Hawaii, is approximately 2,000 miles from the nearest continental area. The Stoke's settling times for quartz particles of 10 micra diameter, which are near the mean of those in the sediments, is approximately 2 years for 4,000 meters. (In suggesting these Stoke's Law settling times we have not included any enhancements attributable to the aggregation of particles by filter feeding organisms and a subsequent excretion in larger, more rapidly settling masses). These data demand an *average horizontal westerly* com-

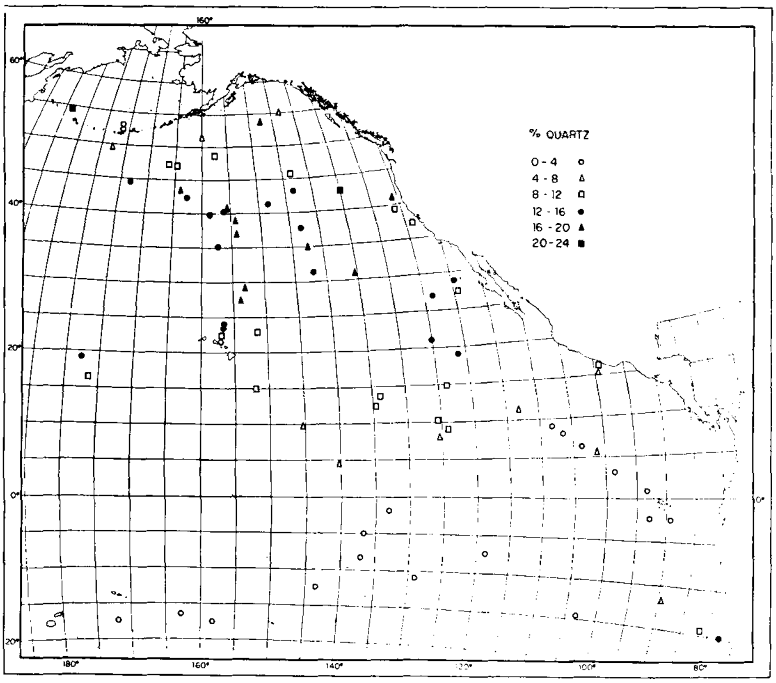

Fig. 2. The concentration of quartz in surface sediment samples from the Eastern Pacific Ocean.

ponent of ocean currents from the North American coast to the deposition site of 0.1 to 0.2 knots for that part of the water column containing the quartz. Such currents have not yet been observed in the descriptive oceanographic studies of this region. Further, the latitudinal variation in the quartz contents is inconsistent with the observed circulation of the North Pacific. Finally, it is difficult to explain the

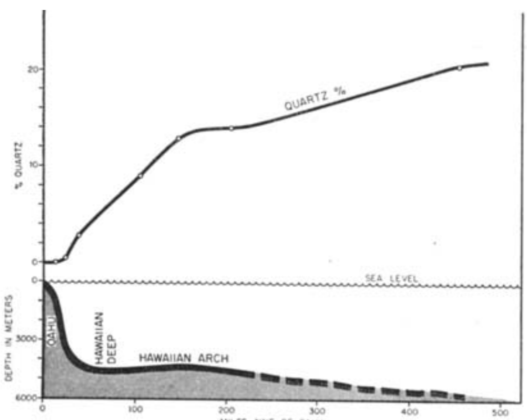

Fig. 3. The dilution of quartz contents in pelagic sediments by weathering products from Oahu Island.

maximum in the quartz concentration in pelagic sediments that are furthest from land by a water transport mechanism. Any water fractionation mechanism that will sort quartz from the more slowly settling, small clay particles would result in a distribution in which quartz would be present in decreasing concentrations with increasing distance from land.

The abyssal plain deposits of the Gulf of Alaska, provide examples of two possible mechanisms for the water transport of quartz: turbidity flow and ice rafting. Two samples, Cusp 5P (Lat. 43°00′N; Long. 134°27′W) and Cusp 11G (Lat. 45°34′N; Long. 143°11′W) situated at approximately 500 and 1,000 miles respectively from the continents, have high quartz contents in the sand and silt sizes and are accompanied by abundant mica which is low or absent from the nearby red clay deposits on topographic highs. The nearshore sample Cusp 5P, contained 22% quartz whereas the more distant deposits contained 10%. The values can most satisfactorily be explained by the sorting action of turbidity currents as described by KUENEN (1950) where the coarser particles are dropped out near the source of flow. The neighboring pelagic clays have values of 15% quartz

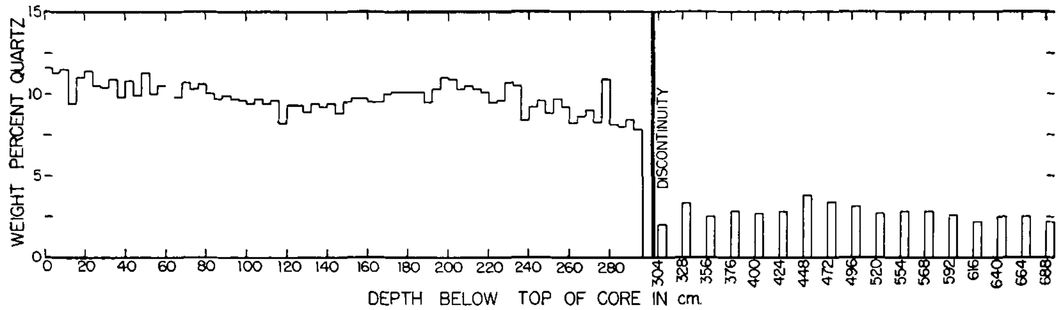

Fig. 4. The quartz concentrations as a function of depth in Capricorn 50 BP (Lat. 14°55'N; Long. 124°12'W). The depth scale is discontinuous after the discontinuity.

and this suggests that the turbidity flow at its extremeties is low in quartz and serves to dilute the quartz contents of the normal pelagic clays. Ice rafting in the Northern Gulf of Alaska, as described by MENARD (1953), introduces a wide variety of poorly sorted materials which give erratic values to the quartz contents in the sediments. For example, Northern Holiday 3, (Lat. 53°22.6'N; Long. 147°13.6'W) contains 17% quartz while nearby NH2 (Lat. 51°34'N; Long. 149°58'W) and NH5 (Lat. 55°7.8'N; Long. 142°55'W) contain 7 and 3% respectively. All of these cores show miscellaneous assemblages of continental pebbles and grit.

Transport of particles by marine organisms appears to be relatively unimportant. The ingestion and subsequent excretion of inorganic particles probably takes place over relatively short periods of time and hence of space. Further, algal transport of significant amounts of sedimentary components appears to be negligible.

In the past not much more than general statements could be made concerning the importance of atmospheric transport of particles to the marine environment, yet there has been a general recognition of the importance of eolian particles in sediments (TWENHOFEL, 1939; CORRENS, 1953). Quantitative estimates of the contribution of such transported particles are lacking, however, a number of lines of evidence from this work converge upon the significance of eolian components in some marine deposits:

(1) The latitudinal variation of quartz corresponds to (a) the intensity of atmospheric fluxes in the troposphere and (b) the amounts of exposed arid regions of the northern hemisphere (Figure 5). The wind movements in the troposphere are dominantly zonal. Both of these parameters would directly influence the amount of dust transported, yet the relative importance of each has not yet been ascertained. As yet there is a paucity of samples from the Southern Hemisphere to complement these observations, and possibly to suggest which of these two parameters is the more significant.

(2) Quartz and other detrital minerals, including feldspars, amphiboles and pyroxenes

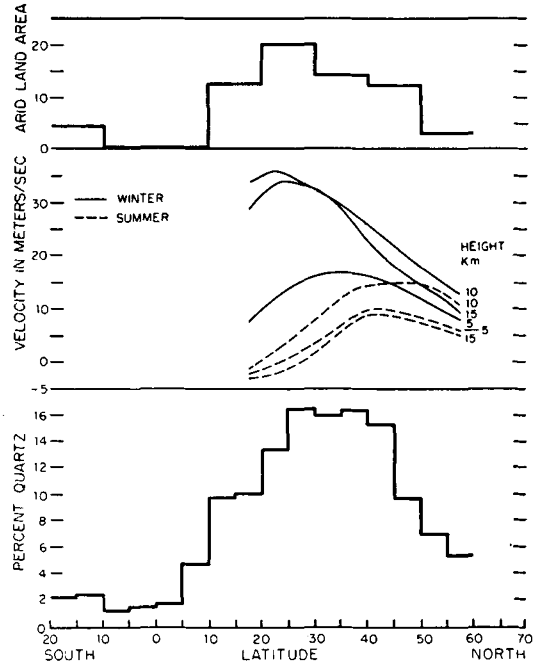

Fig. 5. Lower: The quartz distribution as a function of latitude in sediments from the Eastern Pacific; middle: Mean zonal component of the geostrophic wind. Taken from BYERS (1954); upper: the area of steppe and desert regions in arbitrary units (KÖPPEN and GEIGER, 1936).

have been observed in the guts of filter-feeding pelagic organisms living in the surface waters of the mid-Pacific ocean.

(3) The size distribution of quartz (Figure 1) is similar to observed atmospheric fallout distant from its point of origin. GLAWION (1938) reports a grain size maximum between 3 and 5 micra for Sahara dust collected high in the Swiss Alps. CORRENS (1953) has emphasized the similarity of grain size distribution of marine sediments with atmospheric deposits by matching curves from both sources. His maxima ranged between approximately 10 and 50 micra.

(4) Quartz is consistently reported as a constituent of atmospheric dusts whose mineral compositions are ascertained. KAMPE, WEICKMANN and KEDESDY (1952) detected quartz in addition to clays, lampblack and organic substances in snowcrystal nuclei in New Jersey. LEROUX and TRILLAT (1954) find as common constituents of atmospheric dusts quartz, gypsum, anhydrite, calcite, feldspar, magnetite and hematite. Further, in our laboratories, quartz has been observed in snows from the high coastal mountains of Southern California, and from the Arctic ocean area, in Anarctica and in radioactive rain water from Japan.

Certain deductions can be made from the above evidences that the quartz in most pelagic sediments is atmospherically transported from the continental areas.

Pelagic sediments, deposited below the area of the jet stream in the Northern Hemisphere, are composed to a significant extent of materials that were atmospherically transported. Quartz is not the only mineral found in atmospheric dusts that is refractory to marine weathering processes. Such weathering resistant minerals as feldspar, magnetite and certain clays are *in toto* quantitatively as important as the quartz, in the atmospheric dust, according to the work previously cited. Hence, in pelagic sediments containing 20 % quartz, it is reasonable to assume that around one half of the solid phases are of eolian origin.

Studies of quartz concentrations in areas of turbidity flow can be used to describe the hydraulic flow pattern. For example, the turbidity flows on the Hawaiian archipelagic apron (MENARD, 1956) are apparently limited by the Hawaiian arch with a relief of 600 meters. This not only establishes an upper limit to the extent of the flow, but also establishes that such flows are confined to near bottom waters.

The decrease in quartz content with depth in the North Pacific sediments provides clear evidence for a major climatic change that occurred sometime during the Late Tertiary. These changes are accompanied by changes in the gross chemical composition (REVELLE ET AL, 1955) which have been interpreted by Goldberg and Arrhenius (Geochim. Cosmochim. Acta, in press), as reflecting differences in rates of accumulation of solid phases. Thus, quartz concentrations, coupled with chemical compositions, may provide useful stratigraphic indicators for fossilfree clays.

Finally, this pattern of *natural fallout* may be of some use in studies of *radioactive fallout*. The particles in the normal atmospheric dusts may act as scavangers for the radioactive atoms and molecules and hence the distribution of such guest materials will be influenced both by paths of the host dust particles and subsequent chemical interactions with the environment.

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